Q&A and Damage Functions

Answers prepared by William Nordhaus, Yale University, for NRC Panel on the Social Cost of Carbon, November 13, 2015

The following notes are in two parts. Part I responds to the questions posed to the presenters by the panel. Part II discusses the role of damage functions in three IAMs using the results from the MUP study and inserting those into the DICE-2013R model.

PART I. Responses to questions

1. *How can the characterization of damages used to estimate the SCC be improved over the next 1-3 years through incorporation of existing evidence or changes to modeling approaches?*

Two parts:

(a) The major task that could help (and probably the only one feasible over a 2 year time frame) would be a careful and **comprehensive review of existing damage estimates**. This would involve a team of disinterested analysts who looked at existing studies and synthesized their findings. While this was done several years ago, I do not know of a careful review in the last few years. Also, as you may know, the Tol survey of 2010 was (and I think continues to be) badly flawed. A NRC panel on this would be particularly useful.

(b) However, we must recognize that the research base for impact/damage studies is very thin. Outside of agriculture, sea-level rise, and a few other areas, the research on impacts is vanishingly small relative to its importance. It is clear that the highest medium-run priority in refining the SCC and indeed the whole policy and integrated assessment effort is to **improve the research base of impact studies**. As an example, when I reviewed the estimates of the economic impact of ocean carbonization three years ago, there was essentially zero research on the area.

2. *What improvements can be made with respect to representation of market and non-market damages for particular sectors, catastrophic impacts, adaptation, changes in vulnerability/resiliency, and interactions among these aspects of climate damages?*

Three parts here:

(a) I think the review envisioned in #1 would turn up under-researched and high-priority areas with relatively thin research. So I would look to #1 primarily to answer this question.

(b) My view (prior to #1) based on my reading of the literature is that we should look particularly at areas of potentially large geophysical changes in a coordinated effort of natural and social sciences. These would include the usual suspects such as the two large ice sheets, ocean circulation, and permafrost as examples. But this requires careful planning and scoping.

(c) One of the great challenges in impacts studies is to ensure that they undertake best practice. This involves for example distinguishing weather from climate. As an example, a recent highly publicized article, Burke et al, *Nature,* 12 November 2015, found large damages but appears to base the estimates on variations of weather rather than climate trends. A second issue is ignoring adaptation. This is highlighted in a comparison in the IPCC Fifth Assessment Report of impacts of climate change on agricultural yields with and without adaptation (IPCC, Fifth Report, *Impacts*, p. 498, 515). Third, because of the highly politicized and results-oriented nature of impacts research, this is a field in which the use of "blind statistical analysis" might be particularly useful (Heinrich at http://www-cdf.fnal.gov/physics/statistics/notes/cdf6576_blind.pdf).

3. *What are the technical merits and challenges of using a damage function that aggregates across multiple damage categories relative to explicitly modeling individual damage categories (e.g., sectoral or regional)?*

I think this is beside the point. All damage functions are implicitly or explicitly built up from sectoral studies. To the extent that models contain the sectors (such as agriculture), then it is clearly advantageous to use the sector-specific damage function. Similarly for different regions. So models that have rich regional and sectoral specification will probably want to use the detail. Aggregate models (aggregated either by region or by output) will have to rely on aggregate damages.

One point to recognize is that disaggregation is often harmful and should be undertaken with great care. There are technical requirements under which disaggregation will improve accuracy, such as the correlation structure of measurement errors. (See for example Grunfeld and Griliches, "Is Aggregation Necessarily Bad?" *ReStat,* 1960). Additionally, disaggregation implies greater complexity, and more complicated software, which in turn is likely to introduce software errors. Even greater care should be used when introducing stochastic elements into disaggregated, dynamic, non-linear models. It is good to remember this as you drive your new car, which probably has more code than a Boeing 787.

4. *What criteria can be used to assess the reliability of potential improvements to damage functions used for SCC estimation, with respect to both modeling approach and specific evidence?*

I believe that #1 is the answer to this question. However, the damage estimates in all models are based on an inadequate foundation because of the exceedingly thin research base on which to estimate damage functions. Integrated assessment modelers have often had to improvise damage functions because of the lack of research. This should be an area of active research in climate change.

5. *What research areas are of the highest priority to improve the characterization of damages over time?*

Answered above.

PART II. Damage functions and the SCC

Since this meeting is focused on the role of damage functions in estimates of the SCC, I have used the recent model comparison of the MUP project to see if there is a relationship between the damage functions and the SCC in that study.

1. Background on the MUP study. A study currently underway and in working paper status is a study of uncertainty in climate change using multiple integrated assessment models. (See Kenneth Gillingham, William Nordhaus, David Anthoff, Geoffrey Blanford, Valentina Bosetti, Peter Christensen, Haewon McJeon, John Reilly, Paul Sztorc, "Modeling Uncertainty in Climate Change: A Multi-Model Comparison," Cowles Foundation Discussion Paper No. 2022, October 2015.) The study looks at model and parametric uncertainties for population, total factor productivity, and climate sensitivity and estimates the pdfs of key output variables, including CO_2 concentrations, temperature, damages, and the social cost of carbon (SCC).

   The first stage of the MUP study was model calibration runs, whose outputs include damages, output, temperature, and SCC for three models for two policy scenarios and uncertain states of the world. Using the uncertain states of the world as cross-sections, it is possible to estimate implicit damage functions. These take the damage-output ratios and the temperature increases across different states of the world for the base (uncontrolled) scenarios. They are implicit functions in the sense that they only vary the uncertain parameters of population and TFP growth and allow other intermediate variables (such as the output path to 2100) to change according to the models. Figure 1 shows these functions for 2100 output, damages, and temperature. The damage ratios at 3 °C are 2.5% (DICE), 0.4% (FUND), and 4.0% (WITCH).

2. We can next examine how changes in the damage function would affect estimates of the SCC. For this purpose, I took the DICE-2013R model. I then estimated OLS quadratic equations for the 2100 damage ratios shown in Figure 1. For example, the OLS equation for the FUND model is D/Q = -.001126*T + 0.000818 * T^2 (R^2 = 0.998). I then inserted the coefficients of the quadratic damage equation into the DICE model. Since this is the equivalent of the median, I use that for comparisons. For the model that is closest to the quadratic specification (DICE), the implicit damage function overestimates the quadratic parameter by 6%.

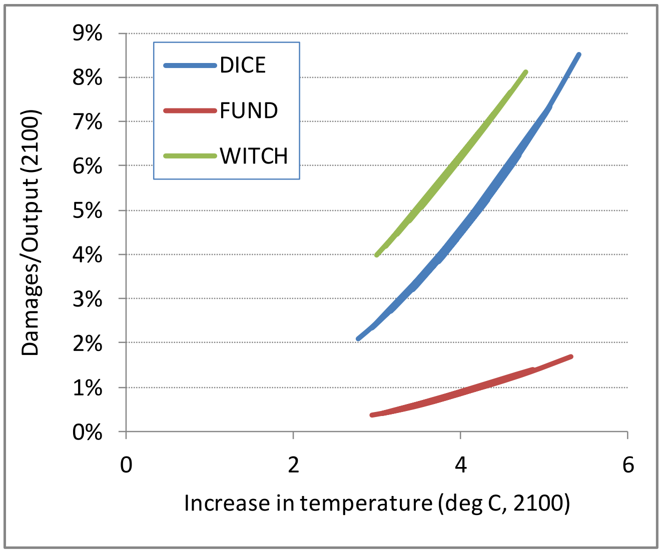

Figure 1. Implicit damage functions for 2100 from MUP runs

3. Table 1 shows the results of the comparisons. The first column shows the damage-output ratio at 3 °C for the implicit damage functions. The second column shows the median SCC for 2020 in the MUP runs (these are generally close to the model baselines). The third column (SCC DICE-MUP) shows the estimated SCC where the implicit damage functions shown in Figure 1 are inserted into the DICE-2013 model. The last column shows the SCC for DICE with the actual rather than the implicit damage function.

These results make it clear that the most of the differences in the SCC across the three models is due to the damage function. The DICE implicit damage function at 3 °C is 6 times that of FUND, while the SCC is 9 times larger. Similarly the WITCH implicit damage function at 3 °C is 9 times that of FUND, while the SCC is 7 times larger than FUND. The balance of the differences is due to model differences, of which discounting is one likely candidate.

Model	D/Q at 3 ˚C	SCC(MUP)	SCC (DICE-MUP)	DICE 2013
FUND	0.4%	2.13	4.83	
WITCH	4.0%	14.96	29.22	
DICE	2.5%	18.36	23.45	18.11

Table 1. Results of comparison of damage functions